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Is the wind a periodical phenomenon? The case of Mexico

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ABSTRACT

Under some author's opinion the wind is not a periodical phenomenon and therefore it is more reasonable to invest in renewable periodical energies as tides. In this paper we have developed a computer application based in MatLab©, that through the FFT (Fast Fourier Transform) analyzes the variations of wind speed amplitude in the time and frequency domain. The data were sampled every 10 min in the period 2000–2008. The data come from 31 Automatic Meteorological Stations (EMAs), the country of Mexico and correspond one per state. The survey shows the representation of spectral–temporal surfaces to long time intervals, as one year or more and denotes seasonal envelopes that alter the pattern at certain times everyday. As a conclusion, the wind has an important periodical component for the country of Mexico, since the fundamental component of the wind speed represents a frequency of 1/24 h^{-1} in a very accurate form throughout the time studied. To harness the wind potential of the country of Mexico it should be kept in mind that there is a minimum wind speed between 8 and 16 h and a maximum close to 24 h.

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Contents

1. Introduction

The necessity of mitigating adverse environmental effects from the use of fossil fuels, volatile fuel prices and improve the quality of life, have developed significant growth in renewable power generation across the world [1]. The importance of implementing tools to support policies to promote the dissemination of these technologies is now a universally accepted standard [2]. The wind energy is one of the most powerful and profitable way to satisfy the demands of sustainable development [3], while the production of wind energy has grown 30% per year over the last 10 years [4].

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The wind is considered as one of intermittent renewable energy [5], and for this reason energy storages systems are needed [6], in terms of energy storage, being the production of hydrogen one of the more efficient [7].

Denny [8] explains that the wind has a variable and unpredictable nature which results in increased challenges for electricity system operators.

Ma et al. [9], say that the random character of wind is significant since the wind speed depends on the terrain and the height, and the unpredictability and variability of the wind power generation is one of the fundamental difficulties faced by power system operators.

Wind studies to evaluate the capacity of the wind potential of a geographic area are of two types: physical models and statistical models. Physical methods have advantages in long-term prediction whereas statistical methods do it well in short-term prediction [9].

Examples of statistic models are applied in Argelia [10], in Turkey [11] or in Minnesota, USA [12]. In Mexico there has been a recent work to determine the wind potential of the state of Veracruz [13] and to predict the wind in the state of Oaxaca [14].

The technique of the spectral analysis through the Fast Fourier Transform (FFT) allows to determine whether a phenomenon has periodic components, based on calculating its harmonic [15]. The use of the FFT representing spectral-temporal surfaces has been used in oceanography, in particularly in the study of hurricane Wilma in Mexico, to determine the temporal evolution of waves, in particular variations associated to the period and trajectory of the waves [16].

The purpose of this paper is to analyze, by applying the FFT representation of spectral–temporal surface, the amplitude variations of wind speed in the time and frequency domain, in order to determine whether there exists a periodic behavior.

2. Materials and methods

2.1. Data

In this work we have used the data from the automatics meteorological stations (EMAs) in the country of Mexico [17]. We have analyzed 31 stations, one per state, the geographic distribution is shown in Fig. 1 and names in Table 1. The data used are a series of records from January 1st 2000 to December 31st 2008, with an interval of 10 min between them.

In Fig. 2 it is shown an example of the data used, corresponding to Presa Emilio López Zamora meteorological station (Baja California Norte state) from 1st-01-2007 to 31st-12-2007.

2.2. Methods

2.2.1. Spectral analysis of the wind

An effective technique for studying the periodicity of natural processes is the analysis in the frequency domain, which determines the distribution of energy depending on the frequency or speed of repeated procedures. When the information is discrete, as the one obtained through sampling techniques that is the most common method, treatment is usually based on the use of discrete Fourier transform or FFT in its optimized version for computing speed. Thus, the Fourier spectrum $H(f)$ of the register denoted by $h(t)$ was obtained by the formula [18]

$$H(f) = \int_{-\infty}^{\infty} h(t)\, e^{-j2\pi ft} dt$$

where f is frequency, t is time and j is the imaginary unit ($j = \sqrt{-1}$). In general, $H(f)$ is a complex quantity called Fourier transform of $h(t)$. $H(f)$ can also be expressed as

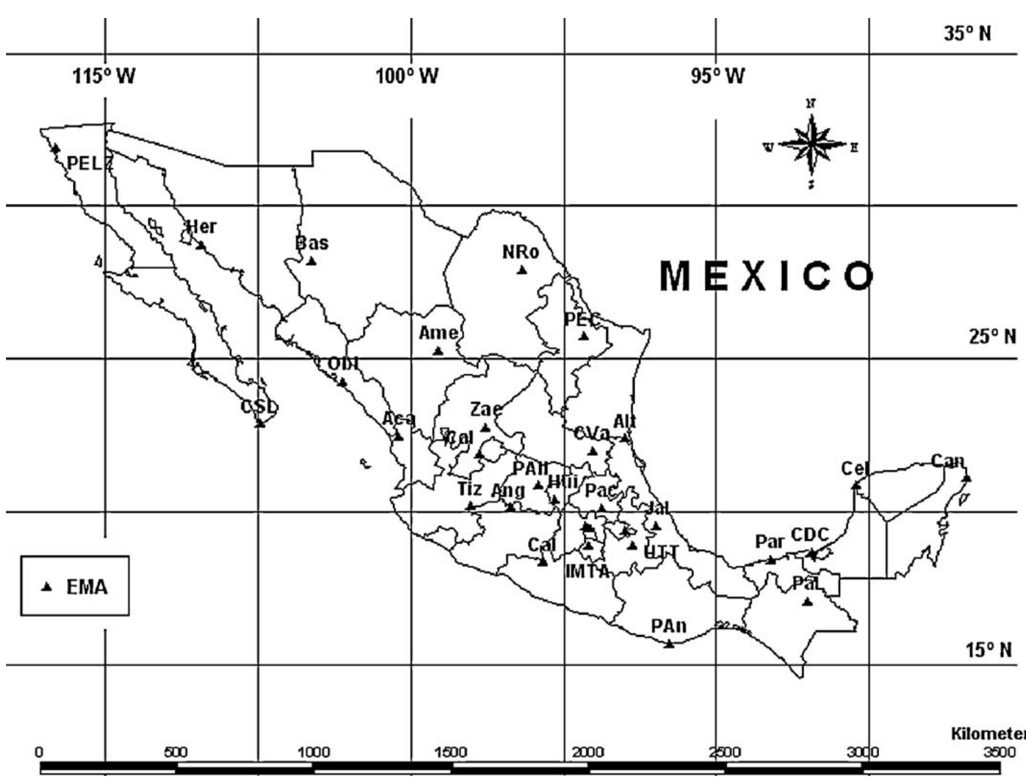

Fig. 1. Geographic distribution of EMA.

Table 1
FT Analysis of EMAs in Mexico.

ID	Name station	State	Period obtained (Hz)
Cal	Calvillo	Aguascalientes	1.157e−005
PELZ	Presa Emilio López Zamora	Baja California Norte	1.157e−005
CSL	Cabo San Lucas	Baja California Sur	1.157e−005
CDC	Ciudad del Carmen	Campeche	1.157e−005
Pal	Palenque	Chiapas	1.157e−005
Bas	Basaseachi	Chihuahua	1.157e−005
NRo	Nueva Rosita	Coahuila	1.157e−005
ENCB	Escuela Nacional de Ciencias Biológicas	Distrito Federal	1.157e−005
Ame	Agustín Melgar	Durango	1.157e−005
PAll	Presa Allende	Guanajuato	1.157e−005
Cal	Ciudad Altamirano	Guerrero	1.157e−005
Pac	Pachuca	Hidalgo	1.157e−005
Tiz	Tizapan	Jalisco	1.157e−005
PMa	Presa Madín	México	1.157e−005
Ang	Angamacutiro	Michoacán	1.157e−005
IMTA	Instituto Mexicano de Tecnología del Agua	Morelos	1.157e−005
Aca	Acaponeta	Nayarit	1.157e−005
PEC	Presa El Cuchillo	Nuevo León	1.157e−005
PAn	Puerto Ángel	Oaxaca	1.157e−005
UTT	Universidad Tecnológica de Tecamachalco	Puebla	1.157e−005
Hui	Huimilpan	Querétaro	1.157e−005
Can	Cancún	Quintana Roo	1.157e−005
CVa	Ciudad Valles	San Luís Potosí	1.157e−005
Obi	Obispo	Sinaloa	1.157e−005
Her	Hermosillo	Sonora	1.157e−005
Par	Paraíso	Tabasco	1.157e−005
Alt	Altamira	Tamaulipas	1.157e−005
Hua	Huamantla	Tlaxcala	1.157e−005
Jal	Jalapa	Veracruz	1.157e−005
Cel	Celestún	Yucatán	1.157e−005
Zac	Zacatecas	Zacatecas	1.157e−005

$$H(f) = R(f) + jI(f) = |H(f)|e^{j\Phi(f)}$$

where $R(f)$ is the real part of $H(f)$ and $I(f)$ is the imaginary part. The amplitude spectrum of $h(t)$ is denoted by $|H(f)|$ and the phase spectrum is denoted by $\Phi(f)$. These are defined as

$$|H(f)| = \sqrt{R^2(f) + I^2(f)}\,\Phi(f) = \tan^{-1}\left(\frac{I(f)}{R(f)}\right)$$

When the amplitude spectrum of $h(t)$ is studied, it is possible to identify the principal harmonic components of the digital record, because they always appear with major amplitude [16]. Frequencies corresponding to principal harmonic components are the frequencies of the tide waves present in the register. These waves are identified visually and their period T ($T = 1/f$) can be read directly from the amplitude spectrum. Thus, these harmonic components are easily identified in the amplitude spectrum. Obviously, spectral analysis can be used to identify and quantify any harmonic component in a digital register. For this reason, the spectral analysis is considered today a standard tool of analysis in many scientific fields.

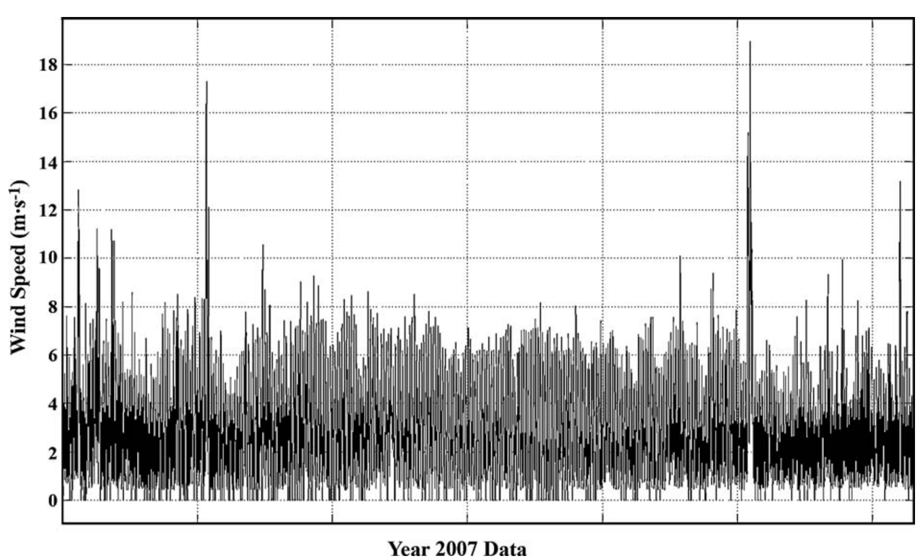

Fig. 2. Example of the data (Presa Emilio López Zamora in Baja California Norte state from 1st-01-2007 to 31st-12-2007).

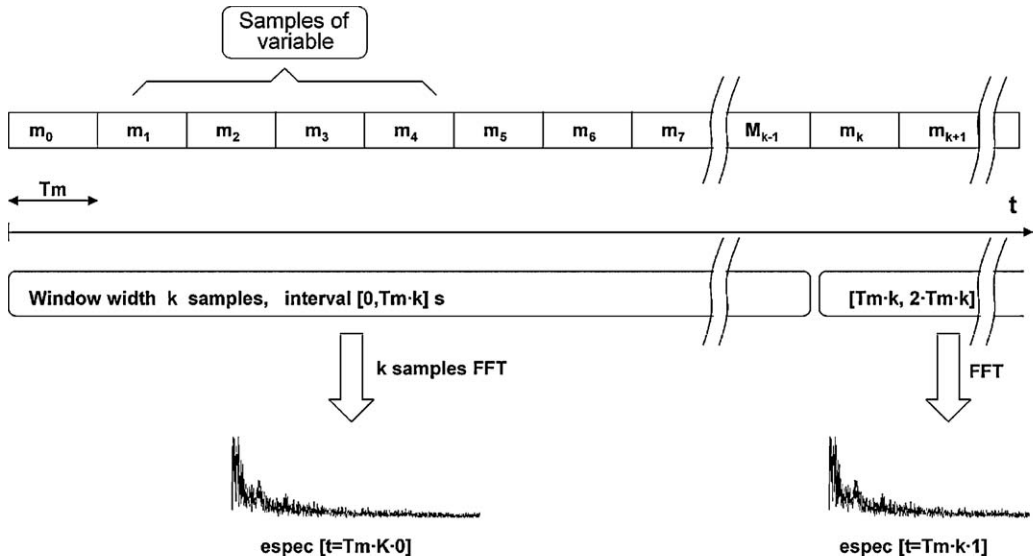

Fig. 3. Outline of sw developed to calculate the FFT.

2.2.2. Characterization of the average day

To characterize the average day for each station in the years 2007 and 2008, we have developed an Excel software application that calculates the average of each 10 min interval for the 24 h to finally obtain the average day of the year. This information is important for the statistical comparison of areas.

3. Theory/calculation

The study of the frequency of wind requires the capture and management of a large amount of data, a sampling period of a few minutes and a period of observation of the order of years to appreciate daily and seasonal periodicity.

The direct application of FFT to the entire data block captured from the wind will not provide very valuable information. It will be necessary to develop a specific process of treatment of these signals that denote the characteristic parameters that can be expected, such as if the existence of periodicity and what type of variations occur along a period of a year.

A sampling period Tm of 10 min in the capture of data allows to collect the most important information of the variable, but generates sets of the order of 50 KS per year.

The direct application of the FFT to the set of samples would provide spectral information that would not reflect seasonal changes, so we have developed the following specific technique of analysis.

The set of samples collected of the variable is fragmented by means of windows of time of appropriate type. A rectangular window introduces distortions due to convolution with $Tm \cdot Sinc(f\,Tm)$ in the domain of frequency. Distortion increases the importance of a less number of samples of the window [19]. Window Hamming is the most suitable for this application. The temporal width of the window is set to: $Tm \cdot k$, obtaining a set of unidimensional vectors of size k of the variable. Then we apply the FFT to each vector, which produces two vectors of size k, corresponding to the module phase respectively. By means of a process of decimation that eliminates the elements of the FFT image we get two vectors of size $K/2$: $espec[t = tm \cdot k \cdot 0]$, $espec[t = tm \cdot k \cdot 1]$ as shown in Fig. 3.

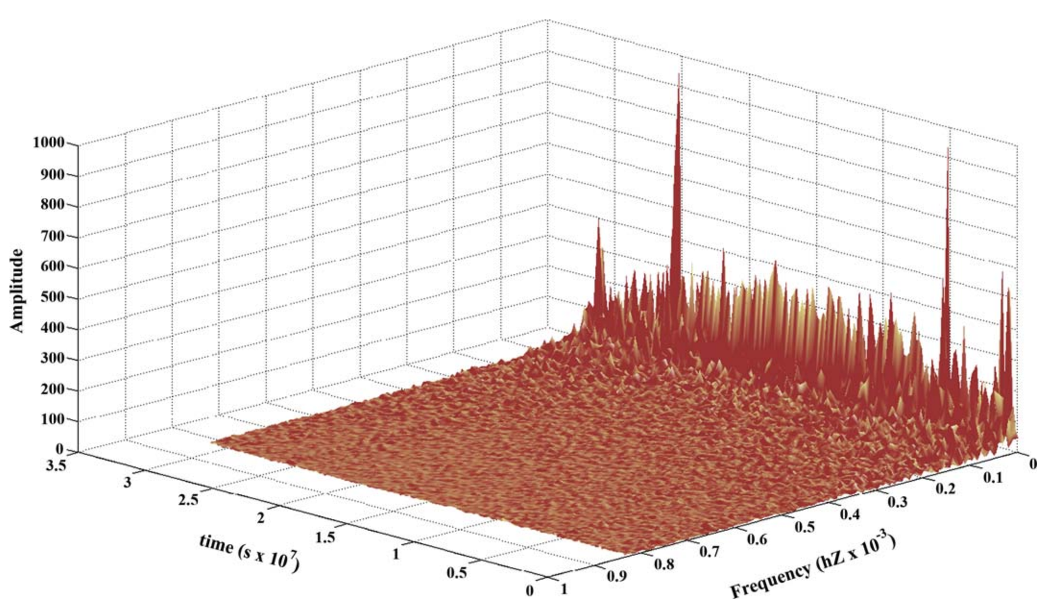

Fig. 4. Sample of spectral–temporal surface for Presa Emilio López Zamora.

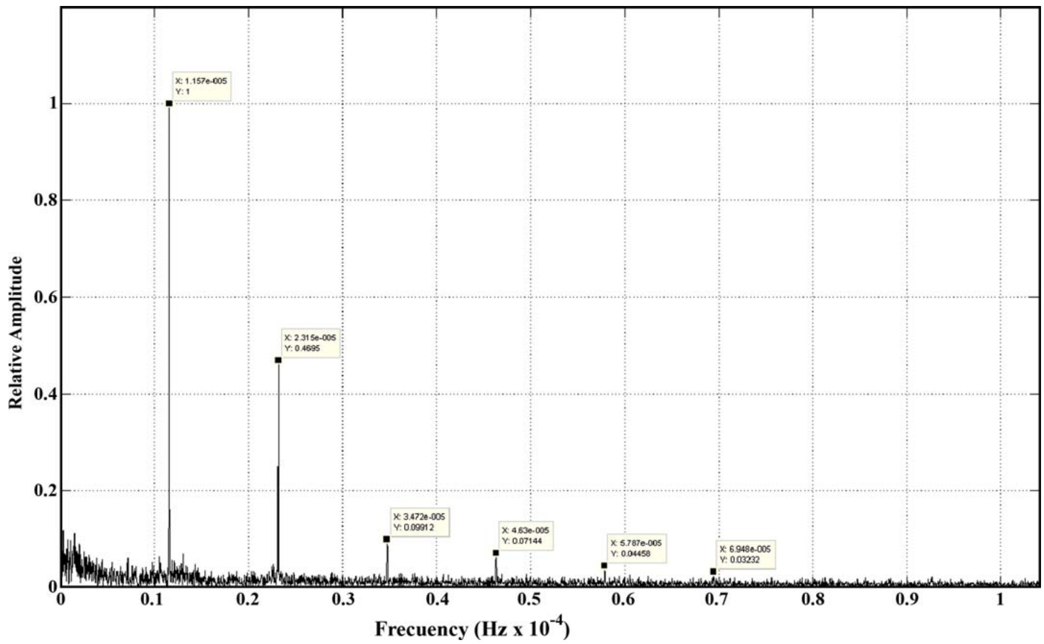

Fig. 5. Sample of FFT analysis for Presa Emilio López Zamora.

After that we generate a two dimensional array Z through the expansion of the vectors by rows spec [$t = tm \cdot K \cdot 0$], *spec* [$t = tm \cdot K \cdot 1$]. . ., corresponding to the FFT module:

$$Z = \begin{bmatrix} es\,pec(t = tm \cdot k \cdot 0) \\ es\,pec(t = tm \cdot k \cdot 1) \\ \ldots \\ es\,pec(t = tm \cdot k \cdot j) \end{bmatrix}$$

Each row vector of the array Z corresponds to the time interval $Tm \cdot k$, 2 $Tm \cdot k$,. . . and thus, for each element zij, j and i correspond to the time and frequency variables, respectively. The array Z allows a representation by a surface as shown in Fig. 4, which corresponds to an interpolated surface built by the Matlab application, using the surfl function. In one of the axis, time is represented, the second one corresponds to the frequency and amplitude is represented in the axis z.

This type of treatment allows the study of the spectrum for a given interval of time and the visualization of the set for the study of the behaviour for a long time or seasonal. The spectral projection of a given period reflects the periodicity of the peaks that are produced using the same frequency value regardless of the period and place of the measure.

4. Results and discussion

4.1. Spectral analysis

Applying the methodology described above we get a spectral–temporal surface for each station from the variations of amplitude of the wind speed in the time and frequency domains. In Fig. 4 we show a typical example of these surfaces for the Emilo Lopez Zamora Reservoir meteorological station, Nuevo Leon state, where there is a concentration of energy at the lowest frequencies. This

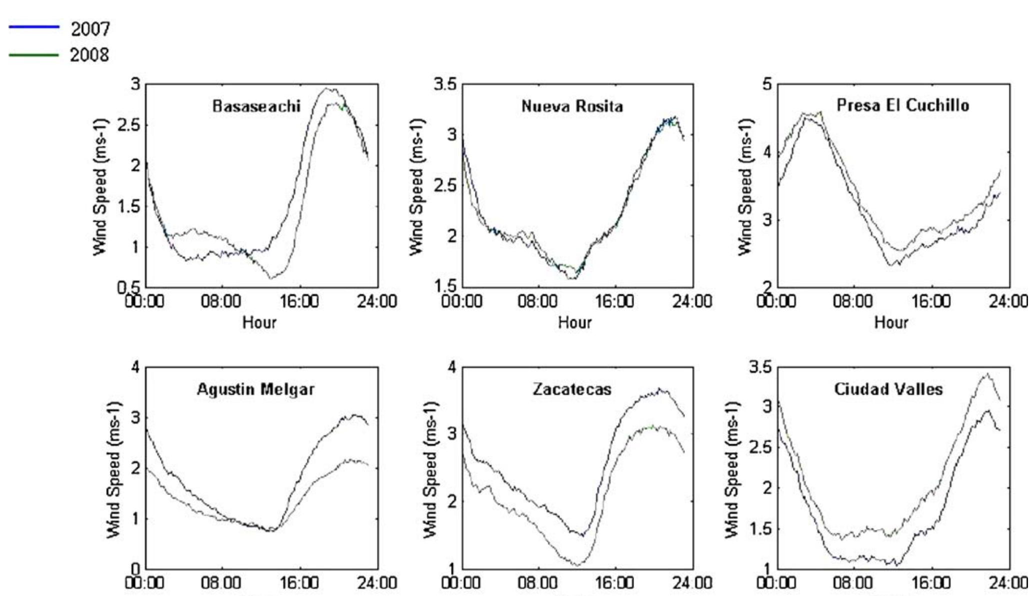

Fig. 6. Average day for the North area of Mexico.

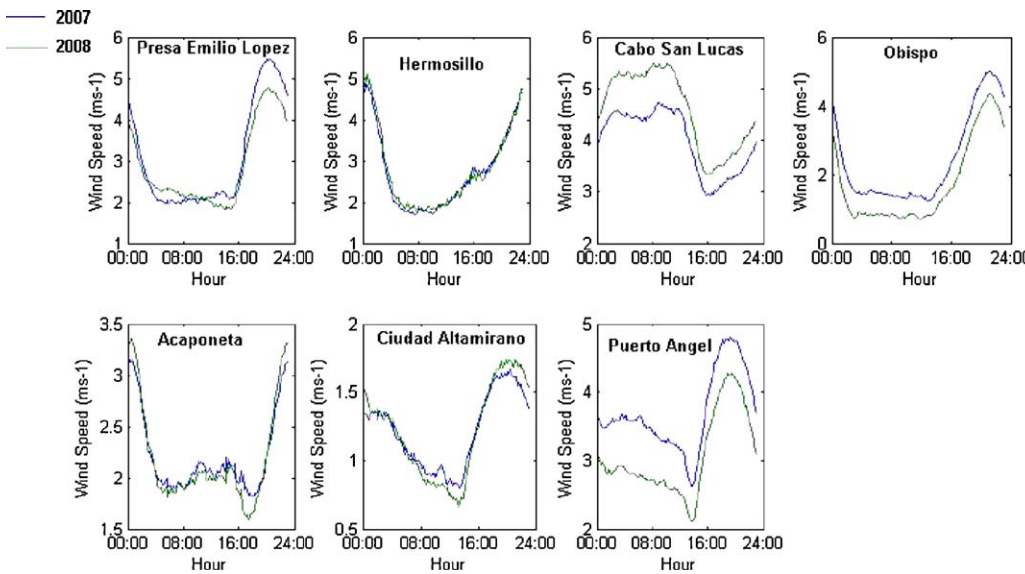

Fig. 7. Average day for the Pacific area of Mexico.

indicates that the phenomenon is not random a priori. Then, to prove if there exist periodicity, it is studied a spectral–temporal surface section in the frequency domain.

In Fig. 5 it is shown an example at the same meteorological station, where the analysis through FFT shows a peak above the noise in the frequency of 1.157e−005 Hz, which is found in all the EMAs studied in the country of Mexico, see Table 1. This frequency corresponds to a period of 24 h. The other peaks are consequence of the design of the software made to show that a function is not sinusoidal.

The survey of the wind periodicity has required capture and manages of a large amount of data, with a sampling period of 10 min and an observation time of order of years to be able to observe daily periodicities.

This implies that an envelope seasonal changes the daily pattern in certain periods. In these isolated cases we have detected temporal intervals of high frequency variability of wind speed that are currently under study, although abnormalities were discarded because the EMA have been presented in different EMAs.

4.2. Average day

Once obtained an average day in every season, these are represented in four graphics, grouped by areas within the country of Mexico: North (Fig. 6), Pacific (Fig. 7), center (Fig. 8) and Gulf of Mexico (Fig. 9).

It is observed that in the north zone, Fig. 6, the average day of the year 2007 has a behavior similar to that one in 2008, i.e., the curve has approximately the same shape. It is also observed that in all these stations, the wind speed has a minimum value between 8 and 16 h, and a peak around the 24 h, which shows the possible phase shifting of the eolic energy generation with the possible daily energetic necessities.

On the other hand it can also observed that the average day of a year is higher than the average day of other year depending on the season, and there does not exist a year with more speed wind than others for every season in this area. We detach the identic behaviour of the average day for the station Nueva Rosita during the two analyzed years. This may implie that the geographic

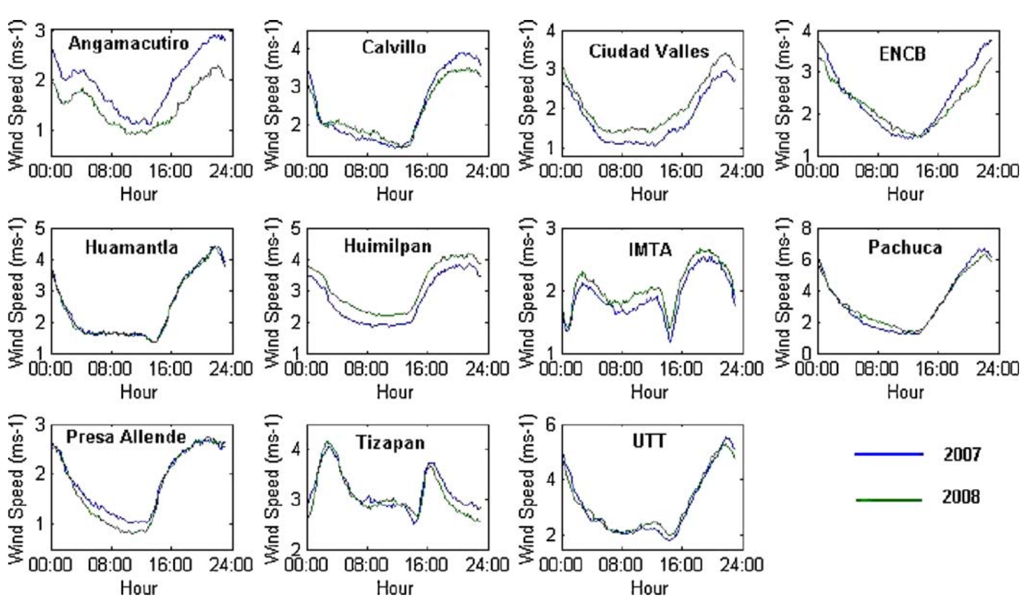

Fig. 8. Average day for the Center area of Mexico.

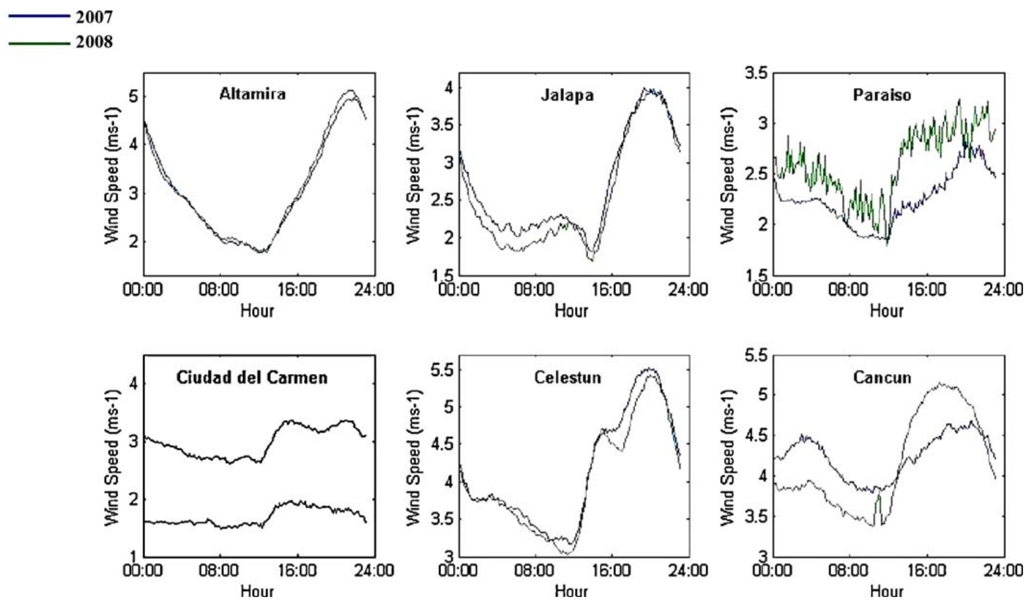

Fig. 9. Average day for the Gulf of Mexico area.

components of this station located in the Durango desert are not so important in the variation of the speed wind year over year than in the rest of the stations.

For the Pacific area, Fig. 7, it is shown a similar behaviour to the North area in the minimum values of the speed wind, excepting for the station of Cape San Lucas, probably due to its special location in the peninsula of Baja California, where it is shown only a minimum at 16:00. Here all the stations have higher speed wind than in 2007, excepting the mentioned of Cape San Lucas. On the other hand the station of Hermosillo, located in the Sonora desert presents an identic behaviour in the two analyzed years, such as it was shown the station of Nueva Rosita.

In the Center area, Fig. 8, the speed wind presents the same minimum from 8:00 to 16:00 than in the other two mentioned areas. Here there does not exist a year with higher speed wind in all the stations. However, we detach that there exist less variations in the speed wind year over year than in the other two areas studied till the present, being the speed wind more stable in this area. Here we also have an station that shows an identical behaviour during the two years, Huamantla, that it is not in a desert but it has a common properties with Hermosillo and Nueva Rosita, and this is that it has a flat geography.

In the Gulf of Mexico area, Fig. 9, there also exist a minimum for 8:00 to 16:00 in the wind speed, excepting Ciudad del Carmen station, whose behaviour is stable during the whole day. Paraiso and Cancun stations show a behaviour year over year less similar between each other that the rest of stations in this area. We detach the difference between the speed wind during the years 2007 and 2008 for Ciudad del Carmen station, showing both of them the same behaviour due probably to the geographic situation, i.e., both are located in an island.

5. Conclusions

In this survey it has been demonstrated that the methodology used through the Fast Fourier Transformed (FFT) in the time and frequency domain is useful to analyze the possible periodic components of the wind speed. The harmonics component obtained through the FFT, besides the fundamental, indicate that the function associated to the wind speed respect time is not sinusoidal.

The survey shows the representation of spectral–temporal surfaces to long time intervals, as one year or more, denote seasonal envelope that alter the pattern at certain times everyday.

The wind have important periodical components in the country of Mexico, such as the fundamental component of the wind speed that presents a frequency of $1/24\,h^{-1}$, very accurate along the period of time studied.

To harness the wind potential of the country of Mexico it should be kept in mind that there is a minimum wind speed between 8 and 16 h and a maximum close to 24 h.

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